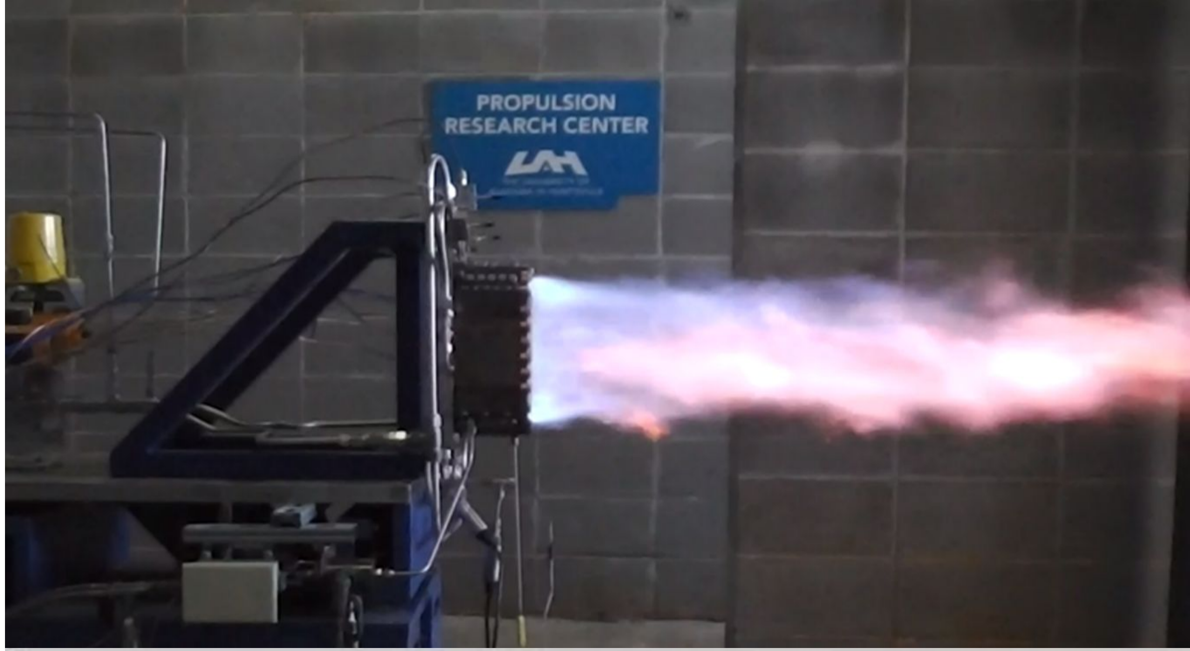
PROPULSION
RESEARCH CENTER
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE



PRC
RDE Update

You are invited to a Zoom webinar

Thursday, Nov 12, 2020
10:00 - 11:00 AM [CST]

Topic:
RDE Virtual Update

Hosted by
Dr. Robert Frederick, PRC Director

Panelists:
Dr. Gabe Xu, UAH
Evan Unruh, UAH
Scott Claflin, Aerojet Rocketdyne
John Bennewitz, AFRL

PROPULSION
RESEARCH CENTER

UAH Propulsion Research Center

- Next Year, The Propulsion Research Center will celebrate it 30th year at The University of Alabama in Huntsville
- Over the past 29 years the PRC has assisted students completing over 270 advanced degrees fueled by over 50 million dollars of funded research*
- These new PRC Webinars provide updates on recent research results and new research initiatives.

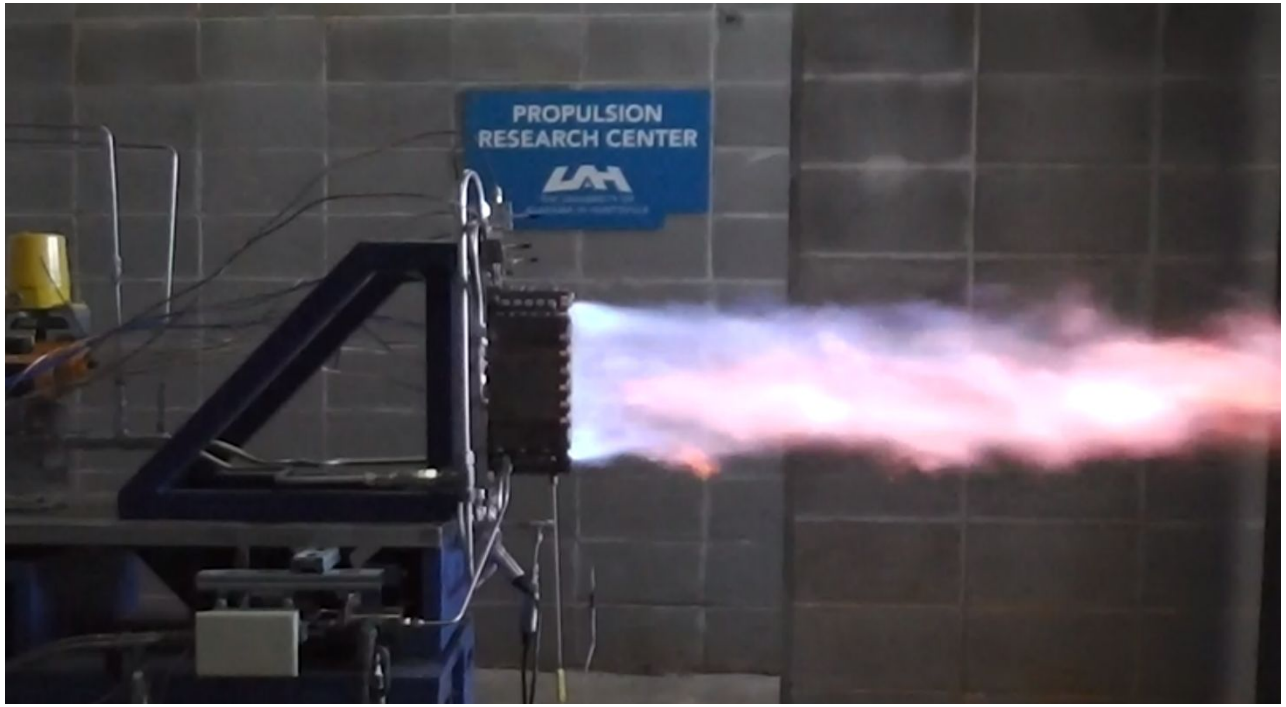
Fall 2019

* Frederick, R.A, Jr., Thomas, L.D., and Ligrani, P.M., "Propulsion Research and Academic Programs at the University of Alabama in Huntsville - PRC Graduate Student Production History,," AIAA Paper 2020-3909, August 2020.

PRC Rotating Detonation Engine Virtual Update

- **Agenda**
  - **Technical Presentation**
  - **Panel Discussion**
  - **Questions and Answers**

- **Today's Panelist**
  - **Dr. Gabe Xu,** Associate Professor of Mechanical and Aerospace Engineering At UAH
  - **Mr. Evan Unruh**, Graduate Research Assistant, UAH
  - **Mr. Scott Claflin**, Aerojet Rocketdyne
  - **Dr. John Bennewitz**, AFRL



Other Items

- A video of this webinar will be posted at www.uah.edu/prc website in two weeks.
- Guest can submit questions to the panel by typing them in before or during the meeting.
- We will be ending shortly before 11:00 AM

PRC Rotating Detonation Engine Virtual Update

Gabe Xu, Evan Unruh,

Michaela Spaulding, David Lineberry, and Robert Frederick

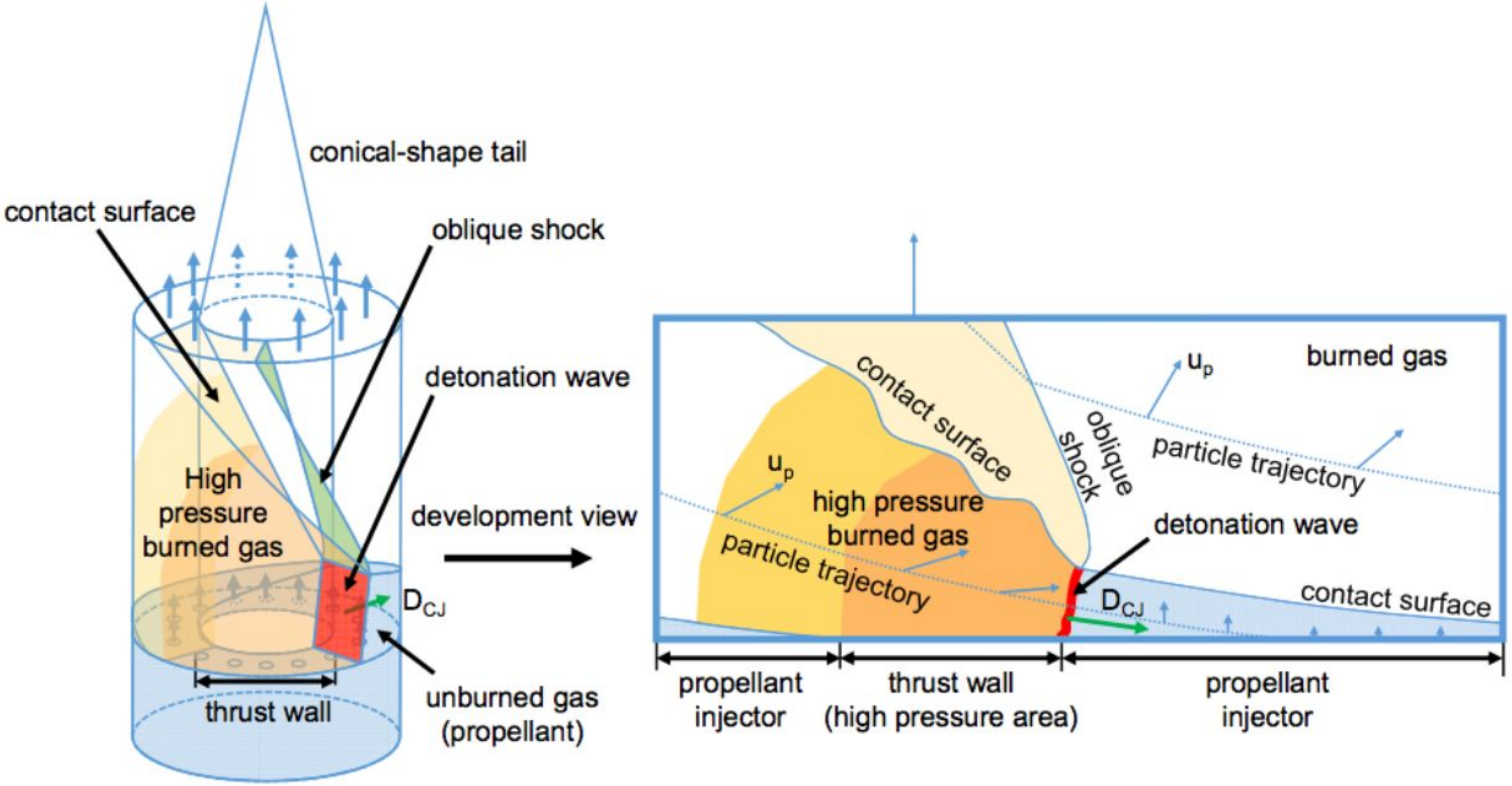
The University of Alabama in Huntsville

November 12, 2020

SME Panelists: Scott Claflin (Aerojet Rockedyne), John Bennewitz (AFRL Edwards)

Rotating Detonation Engine

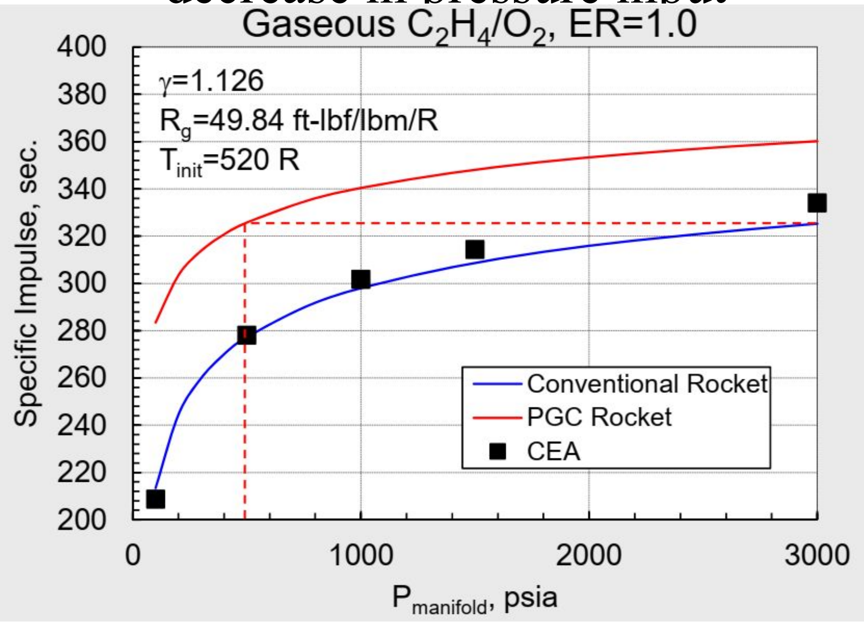
- A supersonic shock wave compresses and heats propellant
- Detonation wave produces constant volume combustion
- Annular geometry allows continuous wave propagation



(Kasahara and Frolov, 25th ICDERS, 2015)

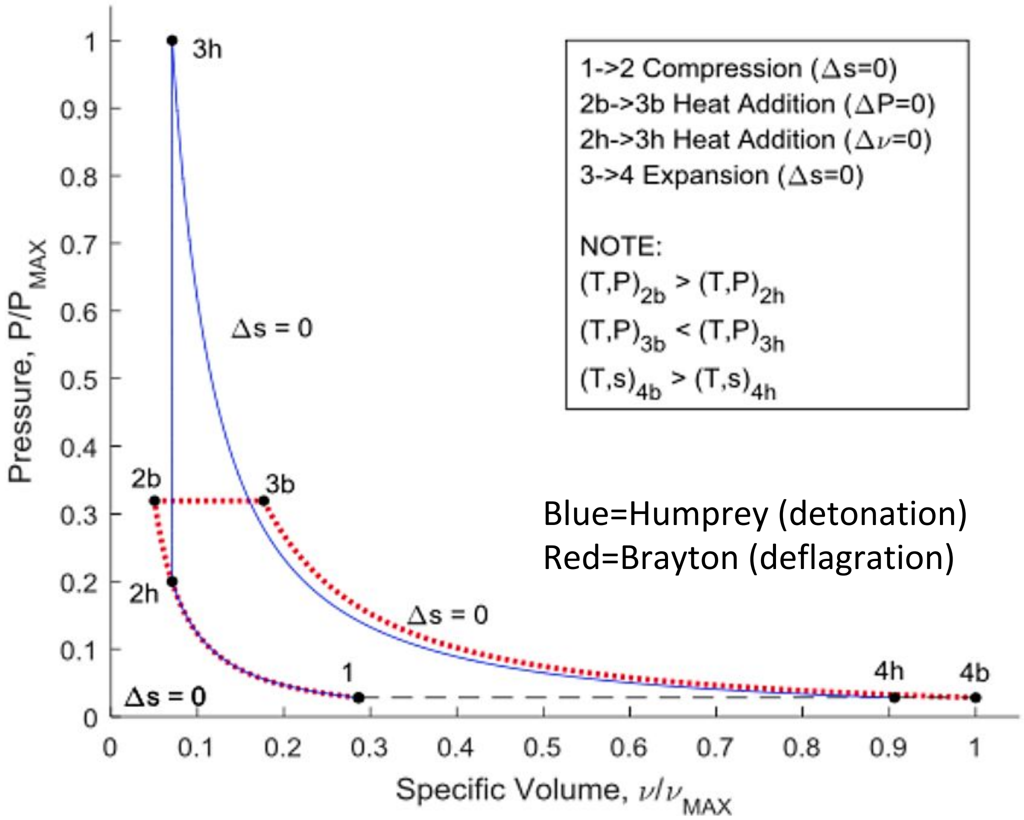
Why RDE

- Conventional deflagration rocket and jet engines at technical plateau
  - Still have advances in materials, manufacturing, propellants, and reliability
- Detonation produces more enthalpy (ideally)
  - Better performance over constant pressure deflagration
  - For rockets ~10% gain work output, and 5-8x decrease in pressure input



(Paxson, DARPA RDE Stakeholders Day, 2016)

Same I_{sp} at 1/6 the pump pressure

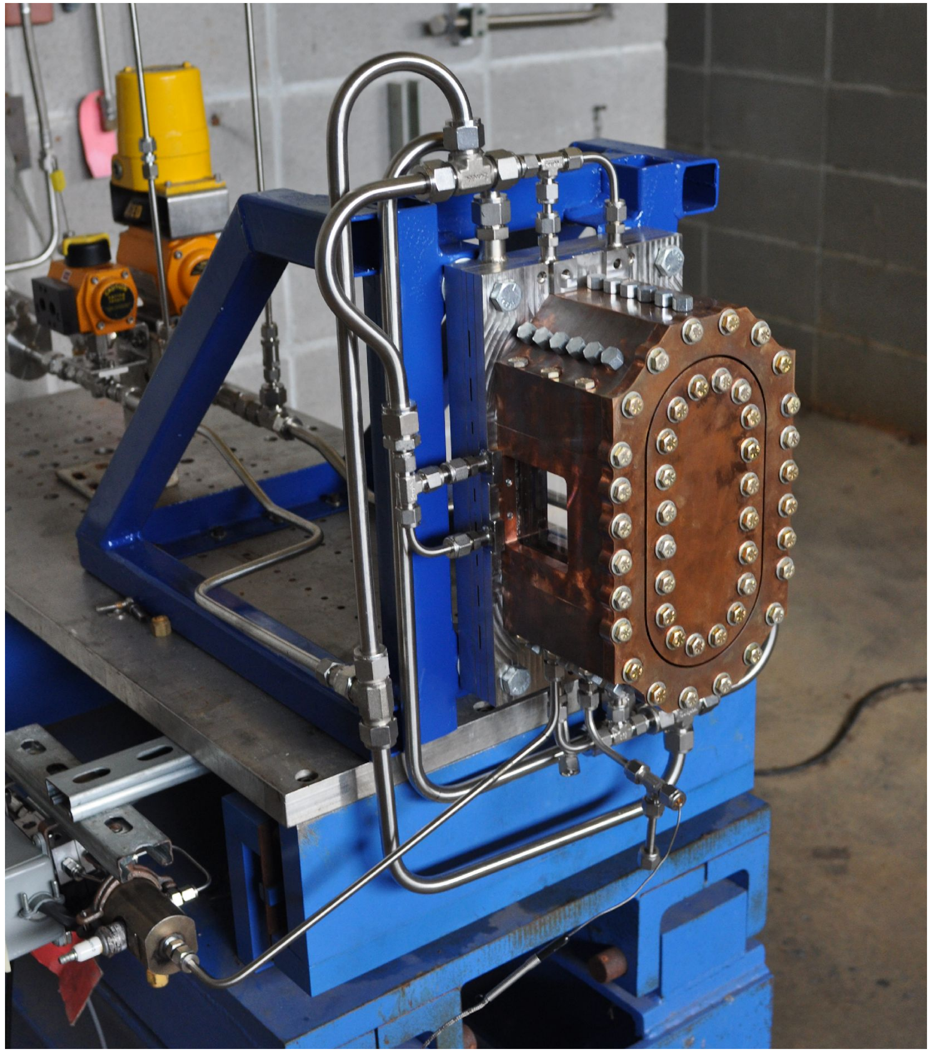


Blue=Humprey (detonation)
Red=Brayton (deflagration)

(Bigler et.al., 53rd AIAA JPC, 2017)

UAH Research

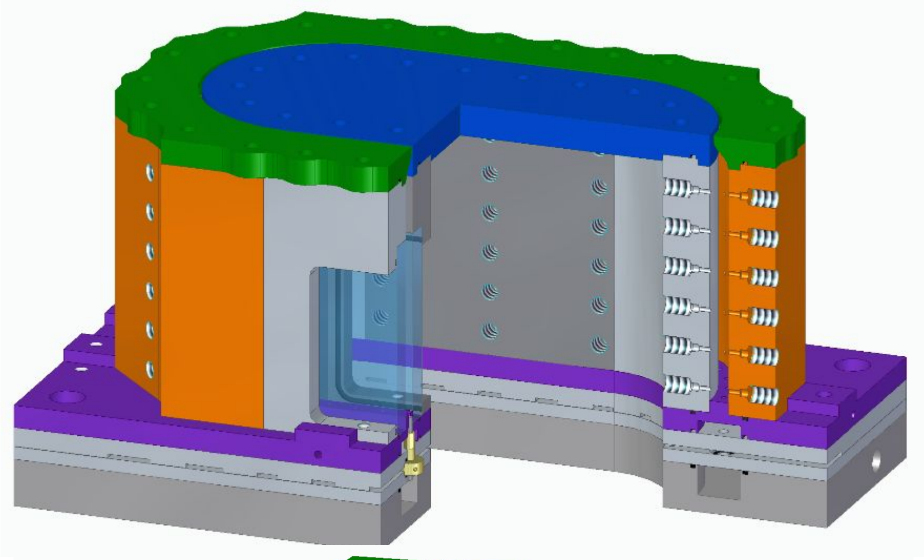
- Initiated Sept 2019 with seed funding from CPU2AL, the Alabama NSF EPSCoR project
  - Design for liquid fuel rocket applications
  - Study transient plasma to enhance/control detonation
- Racetrack RDE
  - Designed and manufactured in-house by M.S. student Evan Unruh
  - Racetrack linear sections allow easier diagnostics to study detonation waves

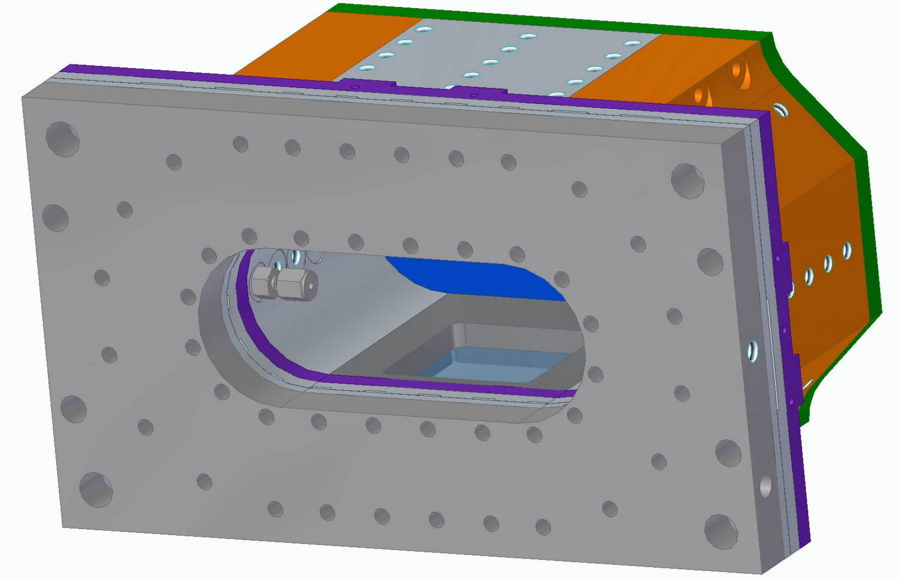


UAH 4-inch RDE Design

Overview:

- 4 inch Channel ID, Stretched into a Racetrack Shape with 4 inch Linear Sections
- 4.6 inch Channel OD
- 4 inch Combustor Length (Injector to Throat)
- Optical Access through Linear Section
- Propellants: LP/GOX, GCH4/GOX
  - Additional Liquid and Gaseous Propellants to be Investigated
- Ox-centered Shear-Coaxial Injectors





Publication:

Development of an Optically Accessible Racetrack-Type Rotating Detonation Rocket Engine

Paper # AIAA 2020-3868

Engine Design: Channel Sizing Process

Select Nominal Propellants and Operating Conditions

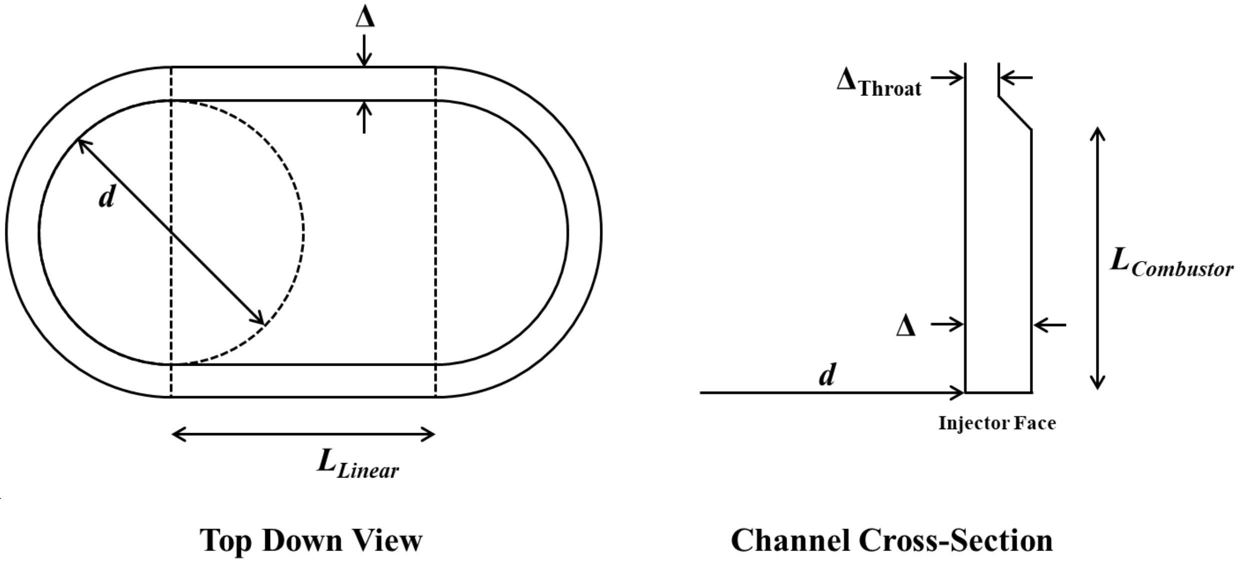
Propellants
- LP/GOX
- Stoich. MR

Chamber Pressure
- 50 psig Nominal

Find Critical Detonation Cell Size (Width) using GALCIT Detonation Toolbox and Gavrikov's Correlation

Det. Cell Width
- ~ 0.050 inch
- ~ 1 mm

Using Det. Cell Width, Find Relevant Chamber Dimensions following Bykovskii's Recommendations



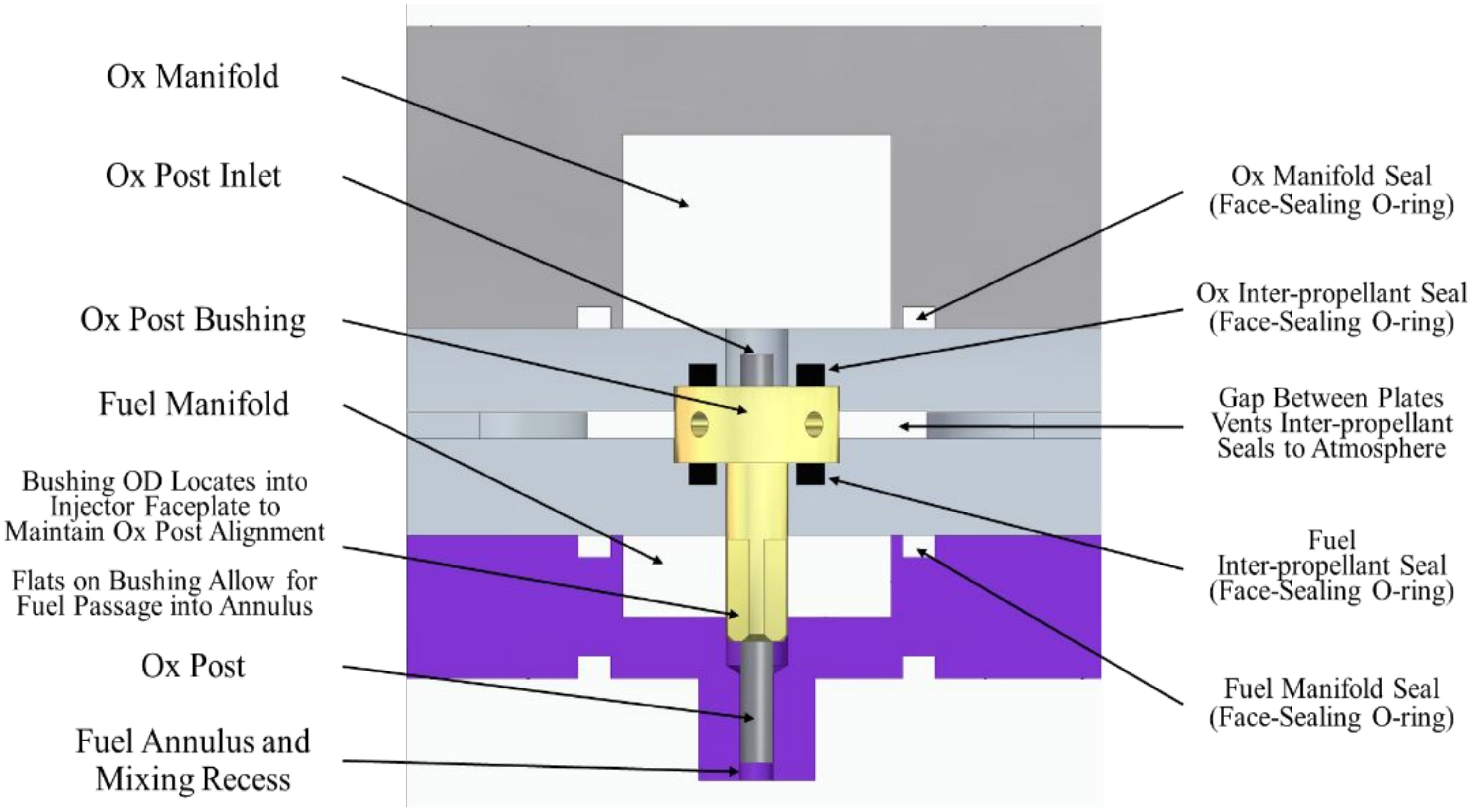
Dimension	Condition of Calculated Value	Calculated Value (in)	Selected Value (in)
λ	Critical	0.0508	N/A
h	Critical	0.8636	N/A
d	Minimum	3.848	4.000
Δ	Minimum	0.1727	0.300
Δ_{Throat}	Optimal	0.065	0.065
$L_{Combustor}$	Optimal	3.454	4.000
L_{Linear}	N/A	N/A	4.000

Injector Design

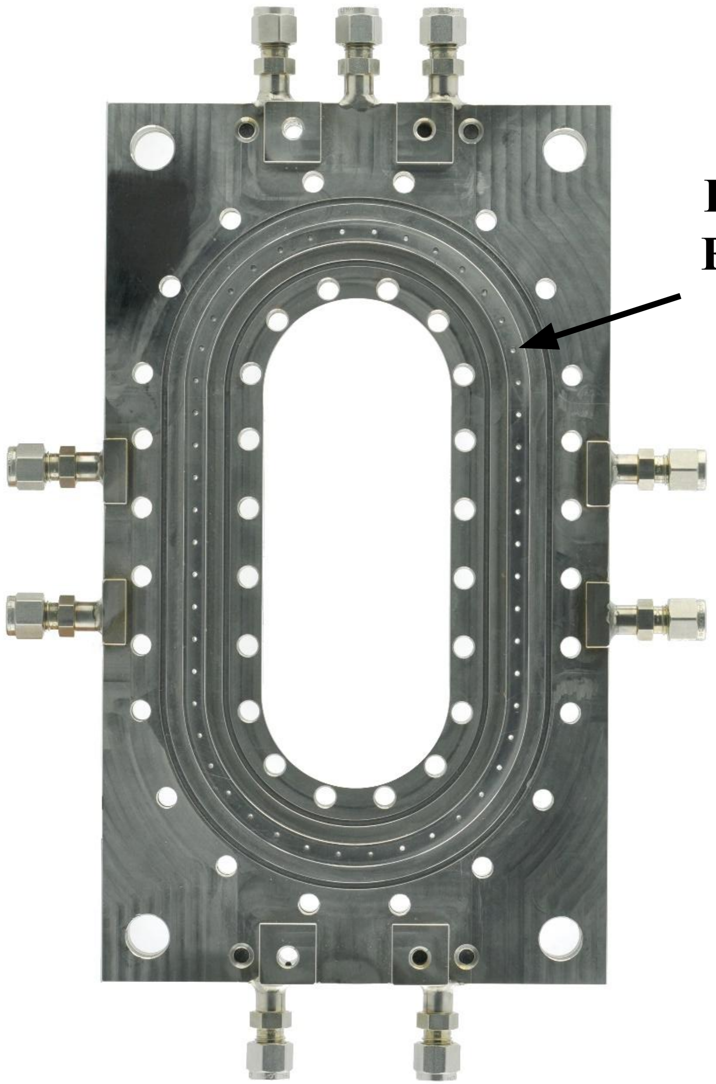
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

50 Elements Spaced Evenly Along Channel Centerline

- Ox-Centered Shear-Coaxial
- Designed following Bazarov's Approach
- Nominal Propellant Flow Rates (Total)
  - Liquid Propane (LP)
    0.138 lbm/sec
  - Gaseous Oxygen (GOX)
    0.5 lbm/sec

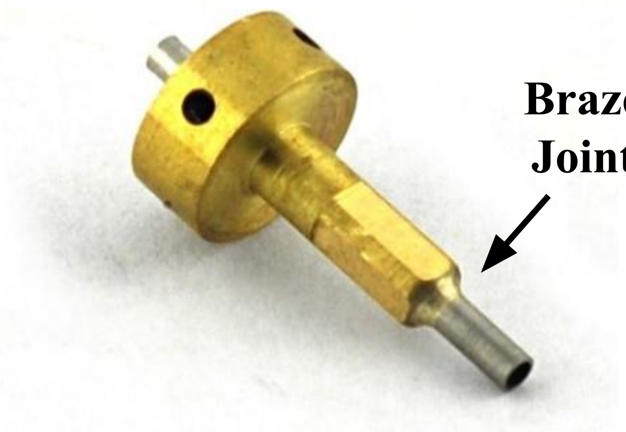


Engine Fabrication: Injector Plate



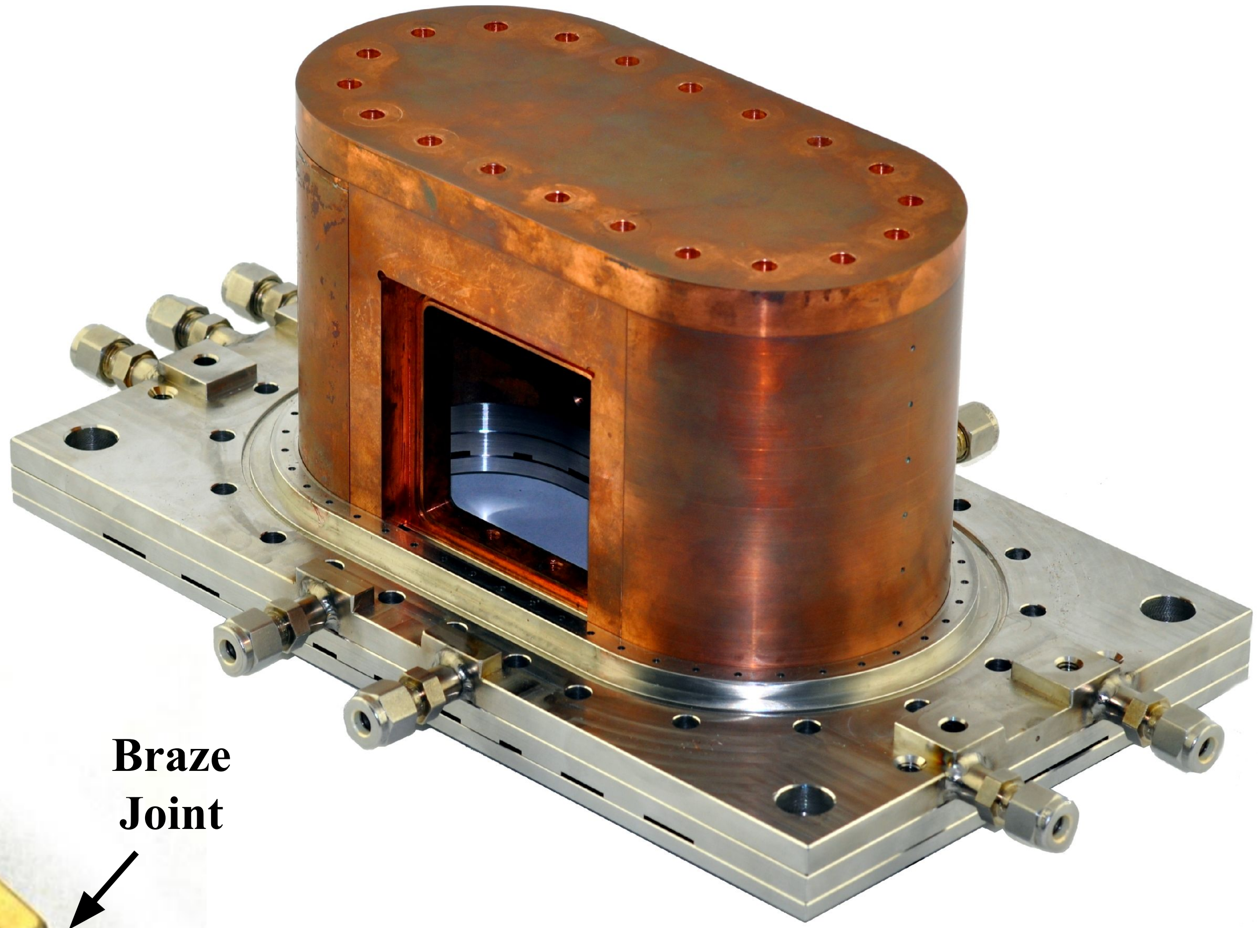
Injector Element Holes

Injector Plate



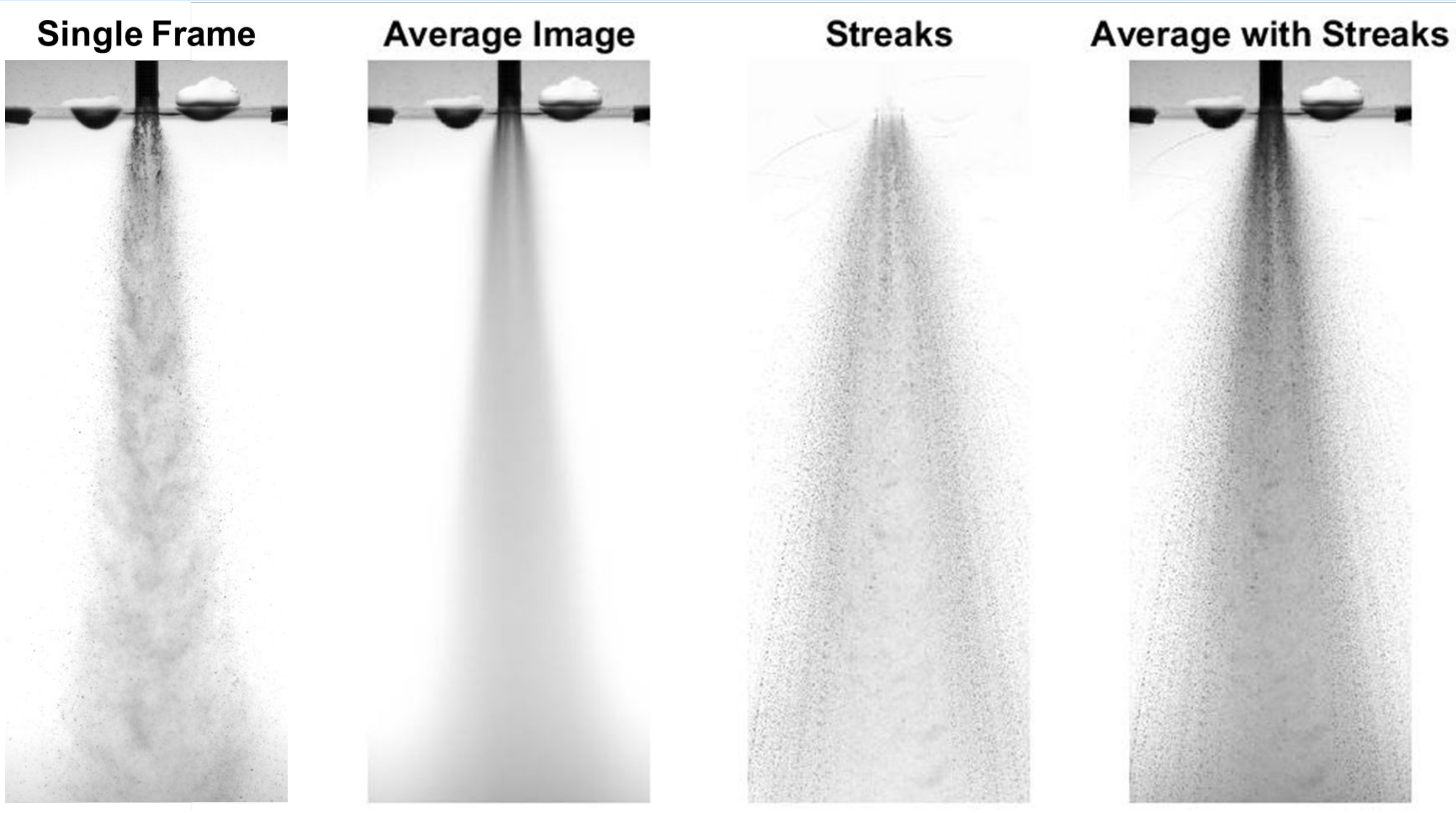
Braze Joint

Injector Element



Injector & Manifold Plates With Combustor Channel Center Body

Prototype Injector Element Cold Flow



Prototype Element Cold Flow with Water and Air
Images from High Speed Video (Single Frame Shown at Left)
Processed to show spray pattern.

Swirl Injector Blast Response

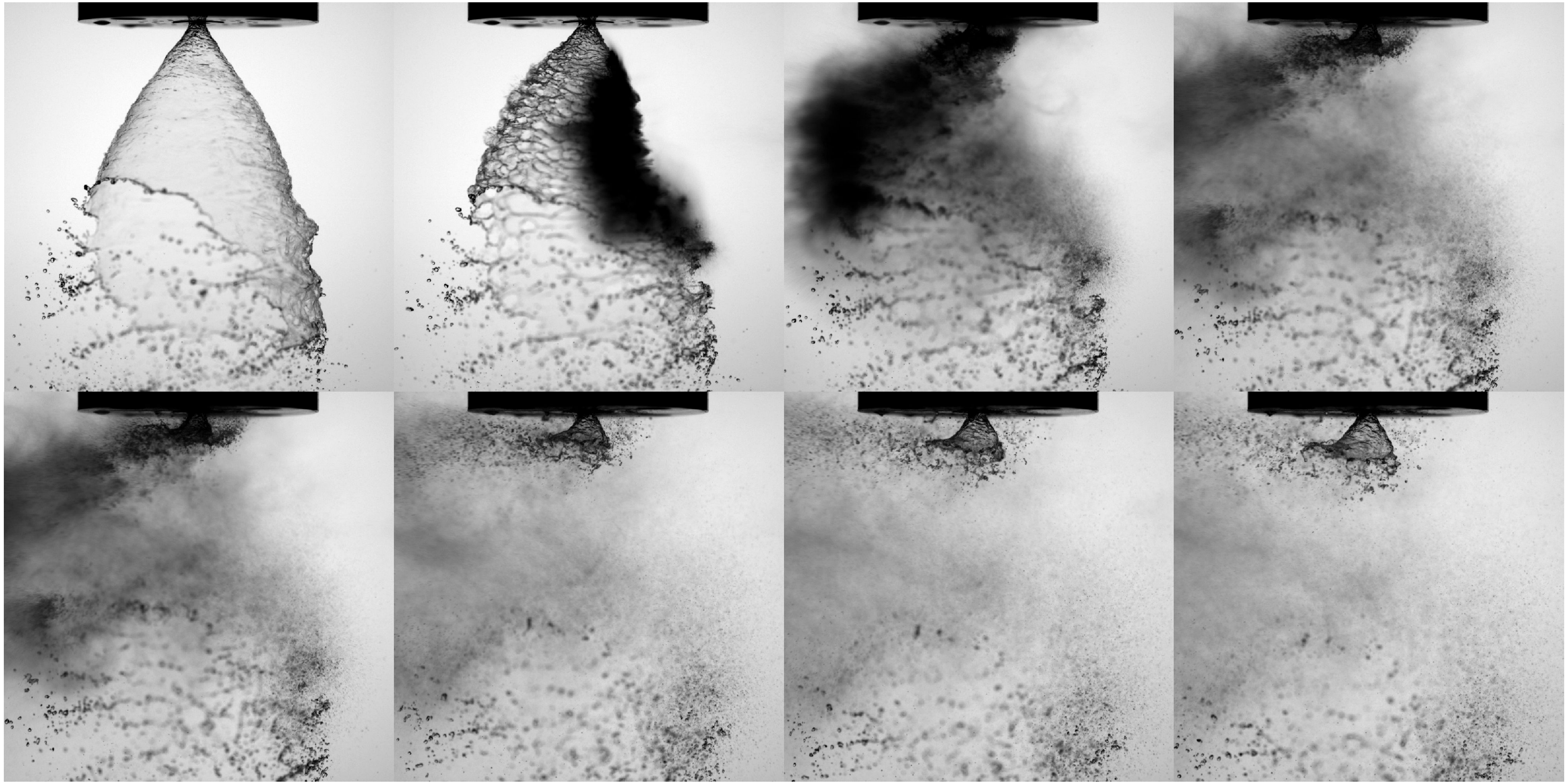
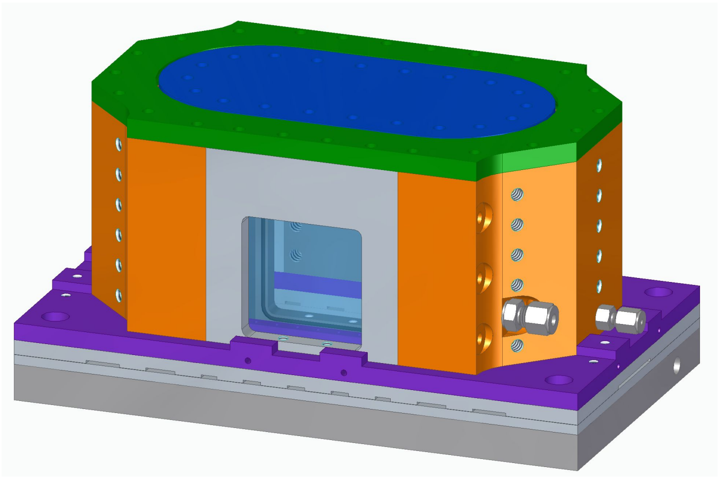


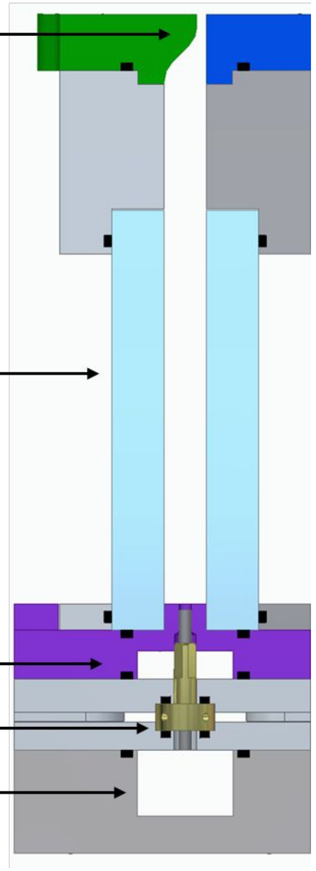
Image Sequence of Swirl Injector Response to Transverse Blast Wave from Shock Tube
(Image Interval: 800 µsec.)
Recorded at the UAH-PRC High Pressure Spray Facility

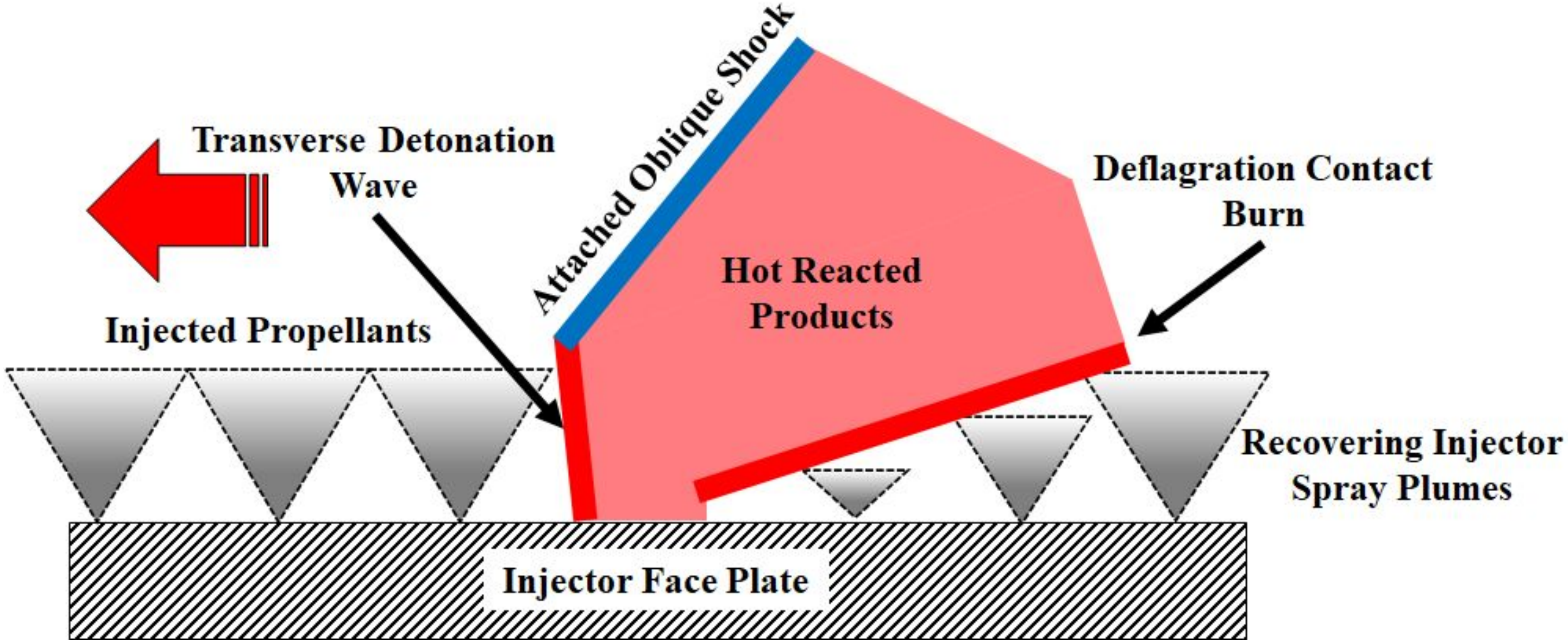
Optical Access



2.5 inch Square Windows in Linear Section

Optical Access Completely through one Linear Section

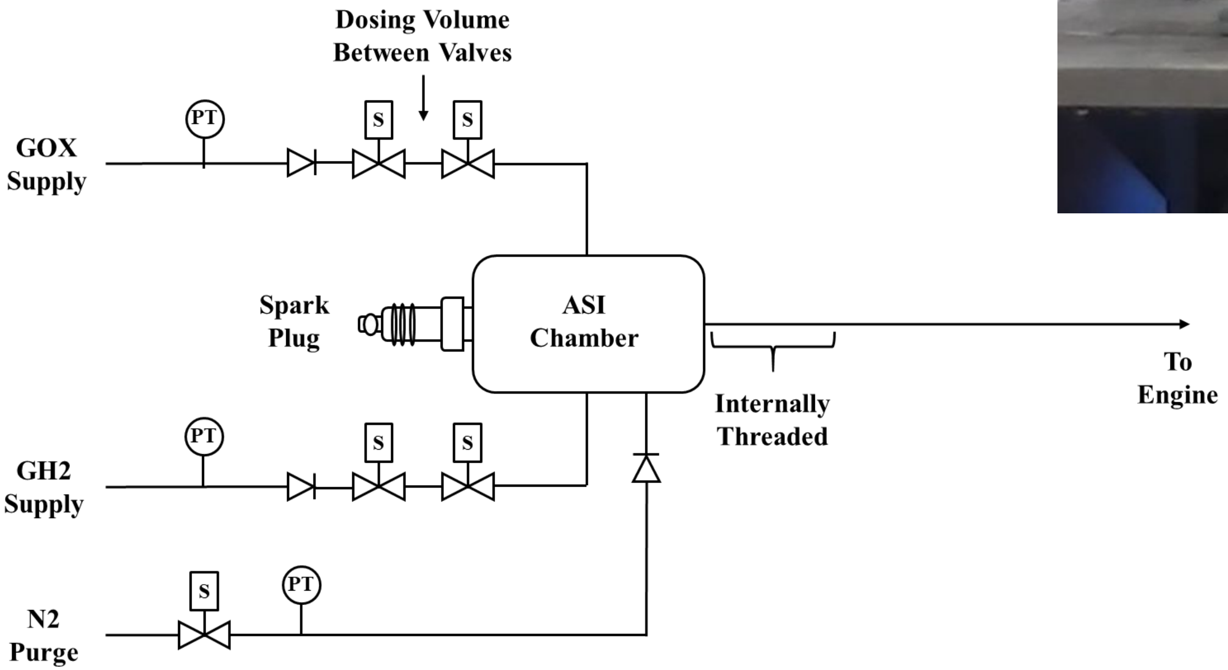


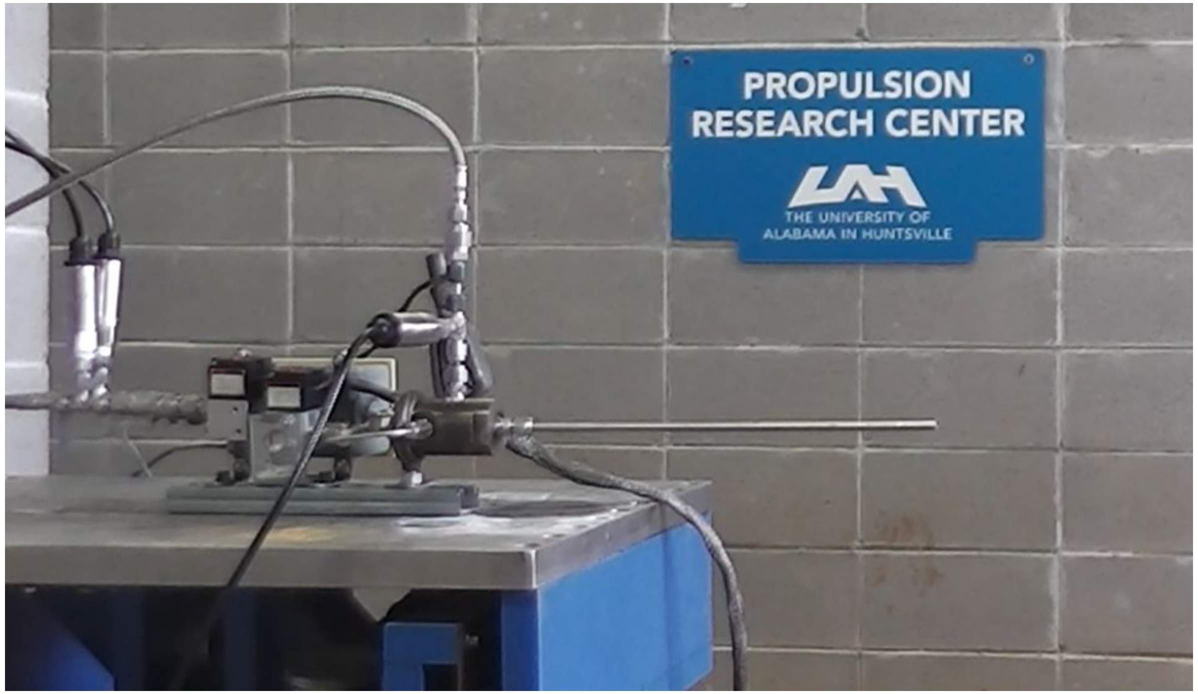


Pre-detonating Igniter

Hydrogen/Oxygen Pre-Detonator

- Modification of Pre-existing Augmented Spark Igniter
- Patterned on AFRL design



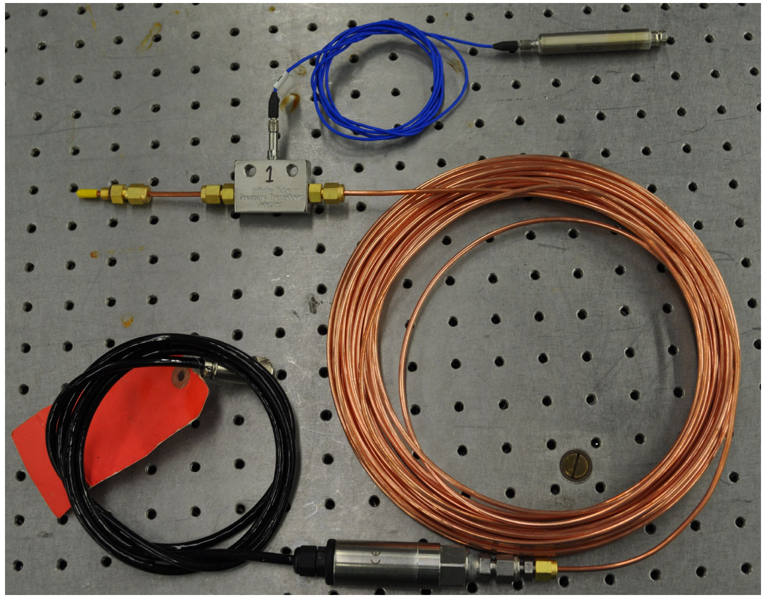


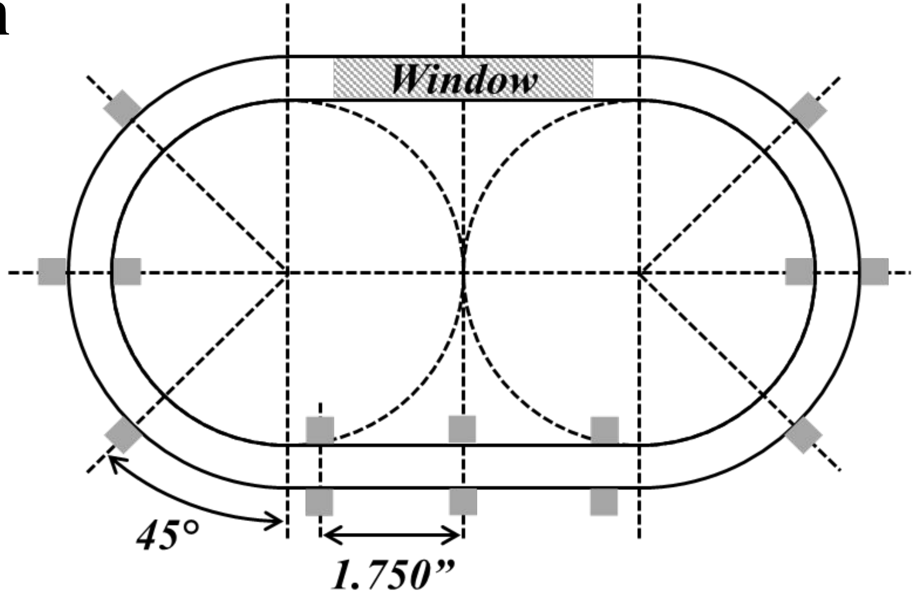
Pre-Detonator Checkout Testing
UAH-PRC Hot Fire Test Stand

Pressure Instrumentation

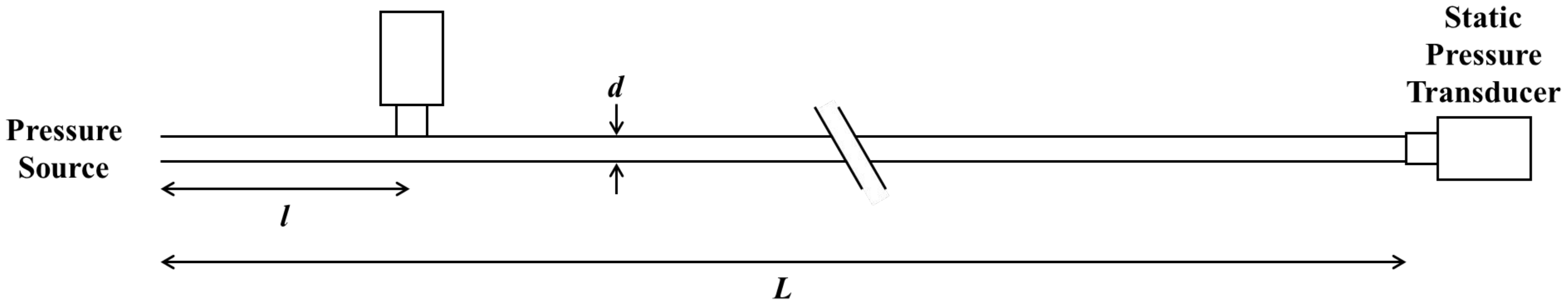
Combined ITP-CTAP Transducer Configuration to Collect Dynamic and Static Pressure Data

- Infinite Tube Pressure (ITP)
  - Dynamic Pressure
- Capillary Tube Attenuated Pressure (CTAP)
  - Static Pressure





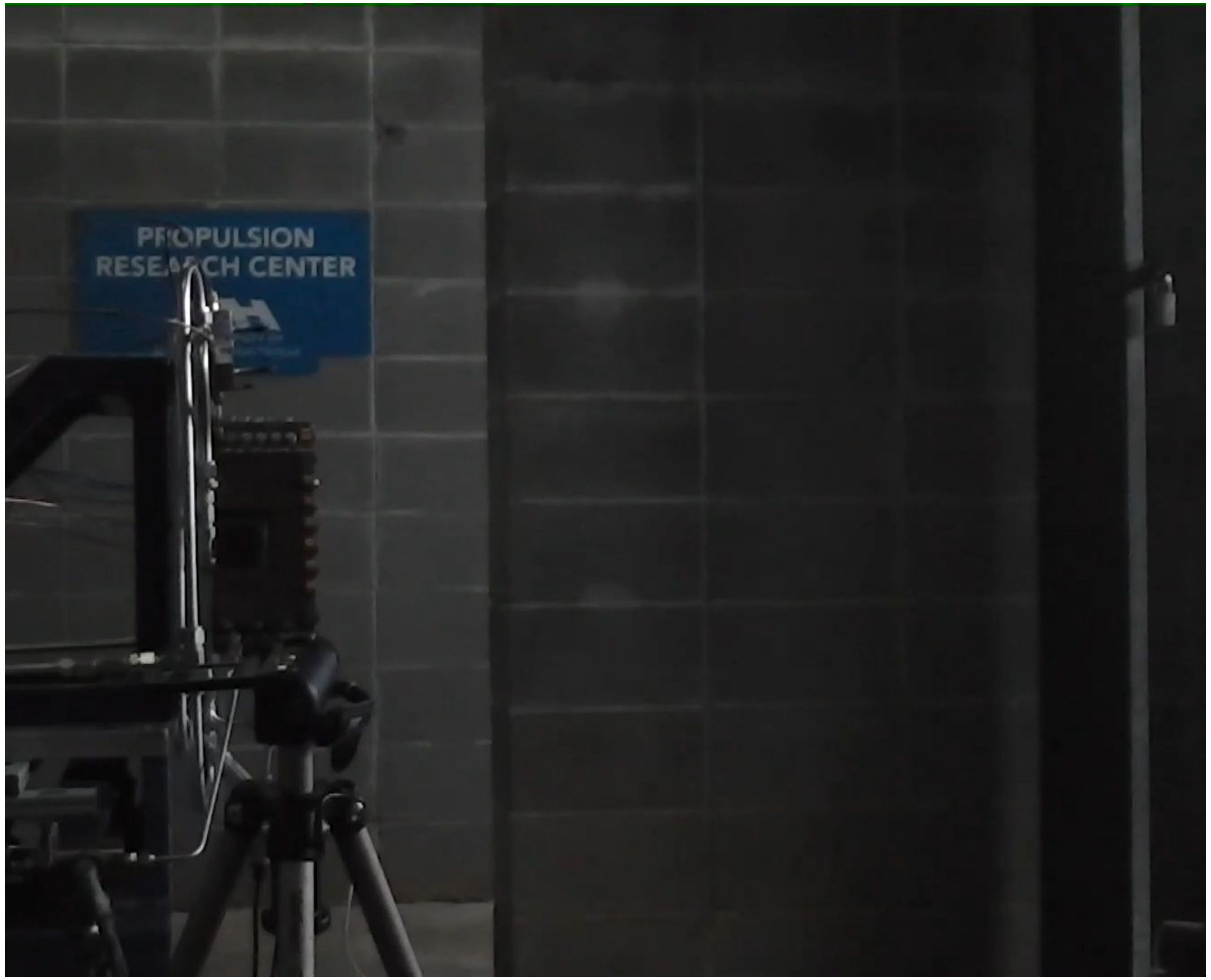
Placement of Pressure Ports Around Perimeter of Channel (Grey Squares)



Testing

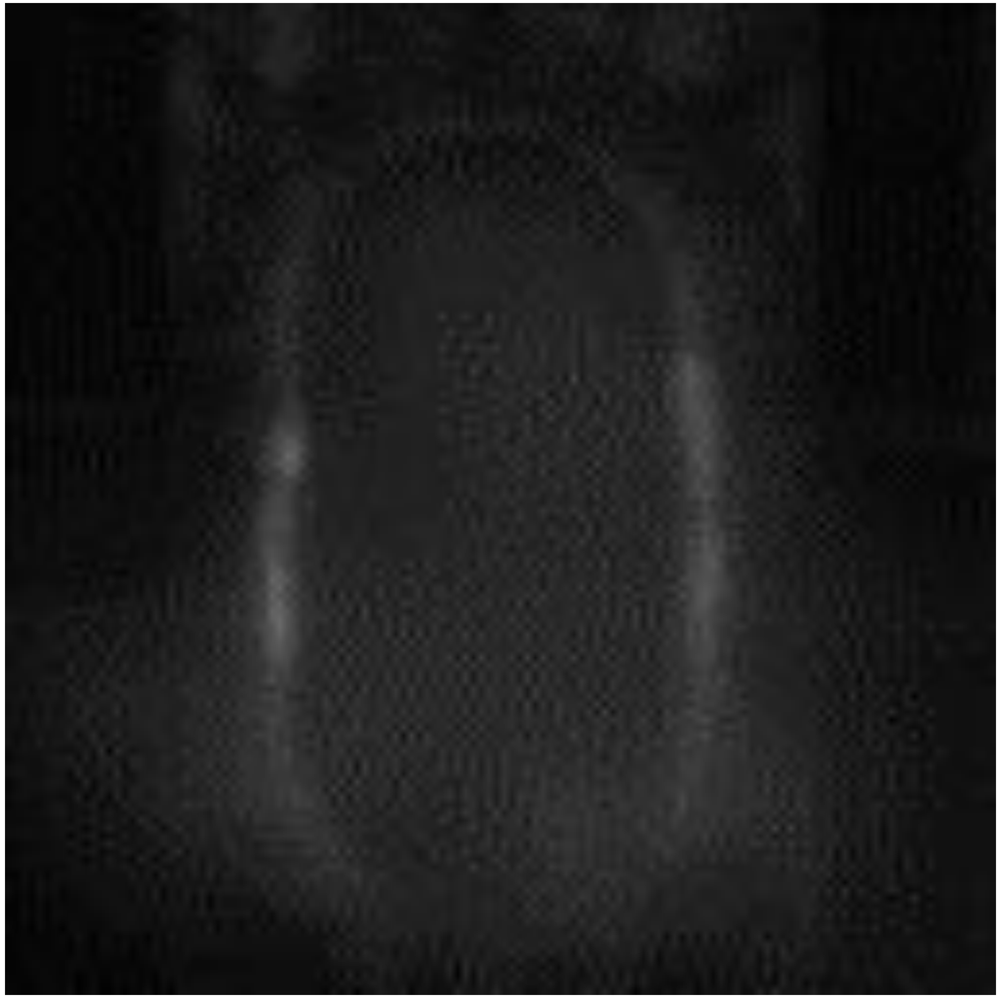
Current Test Campaign

- Hot Fire Testing
  - Initial Characterization testing with LC3H8/GOX and GCH4/GOX
  - Engine Performance
    - Pressures
    - Mass Flow Rates
    - C* (Characteristic Velocity)
  - Detonation Wave Behavior
    - Modes
    - Velocity & Frequency
  - Observation of Wave/Injector Interaction

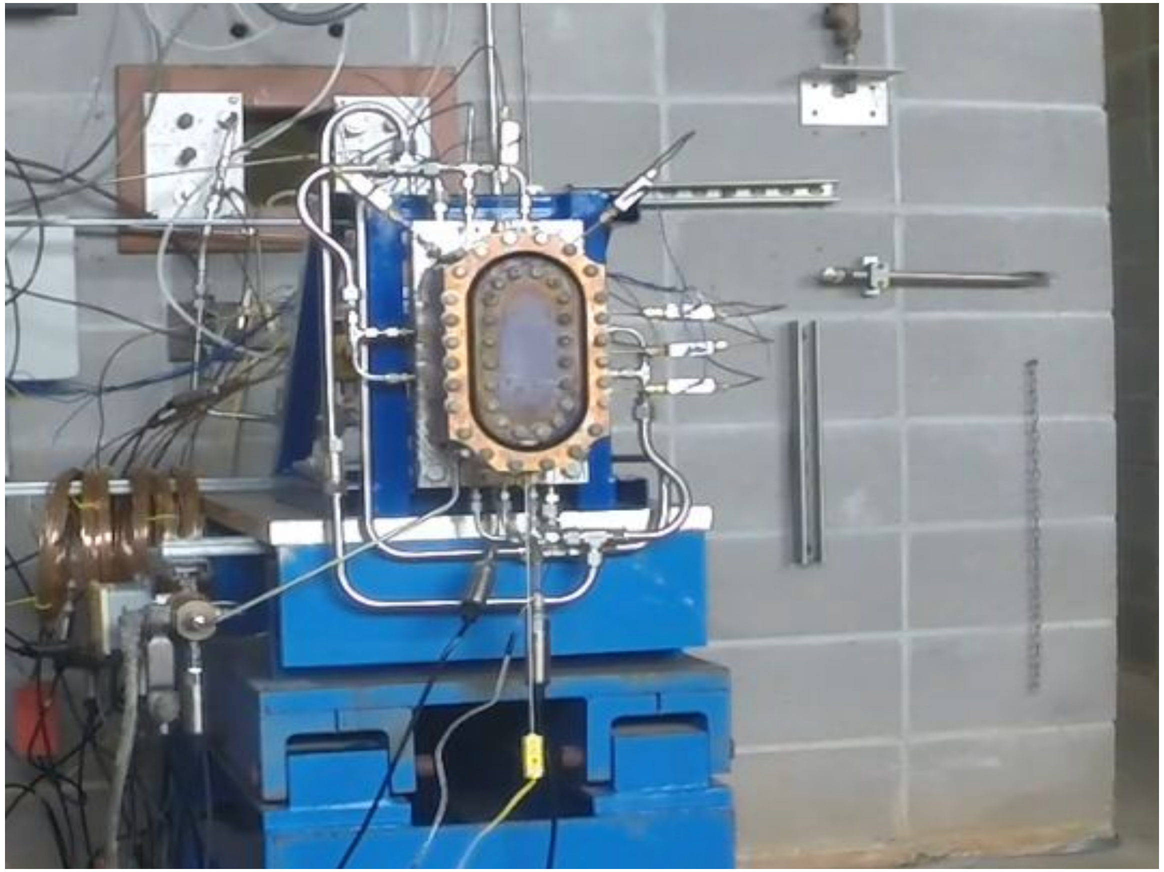


$GCH_4 - GOX \quad \dot{m}_{Total} = 0.2\,\frac{lbm}{sec} \quad \phi = 1.25$

View Down Throat – Moving Det Waves

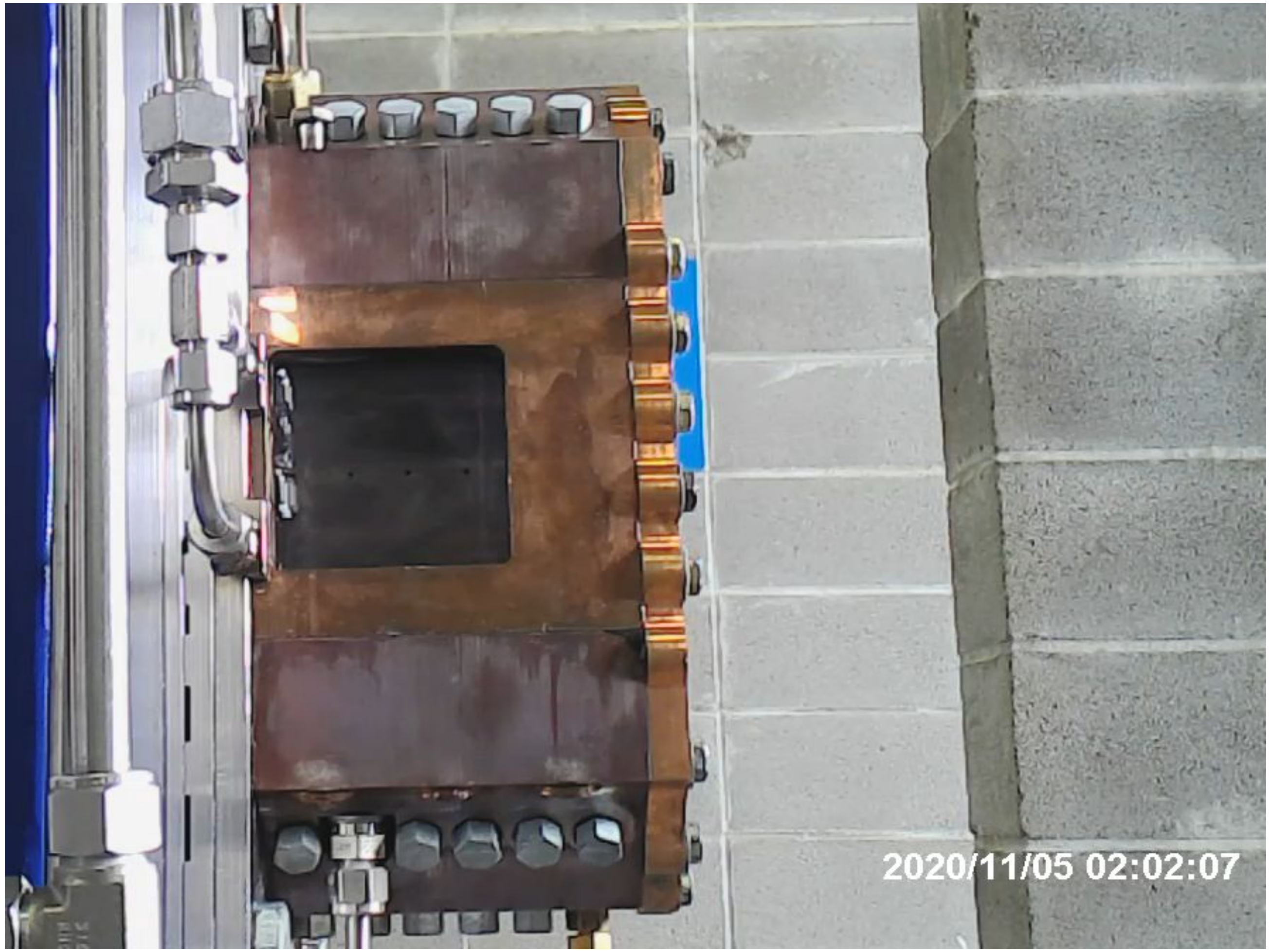


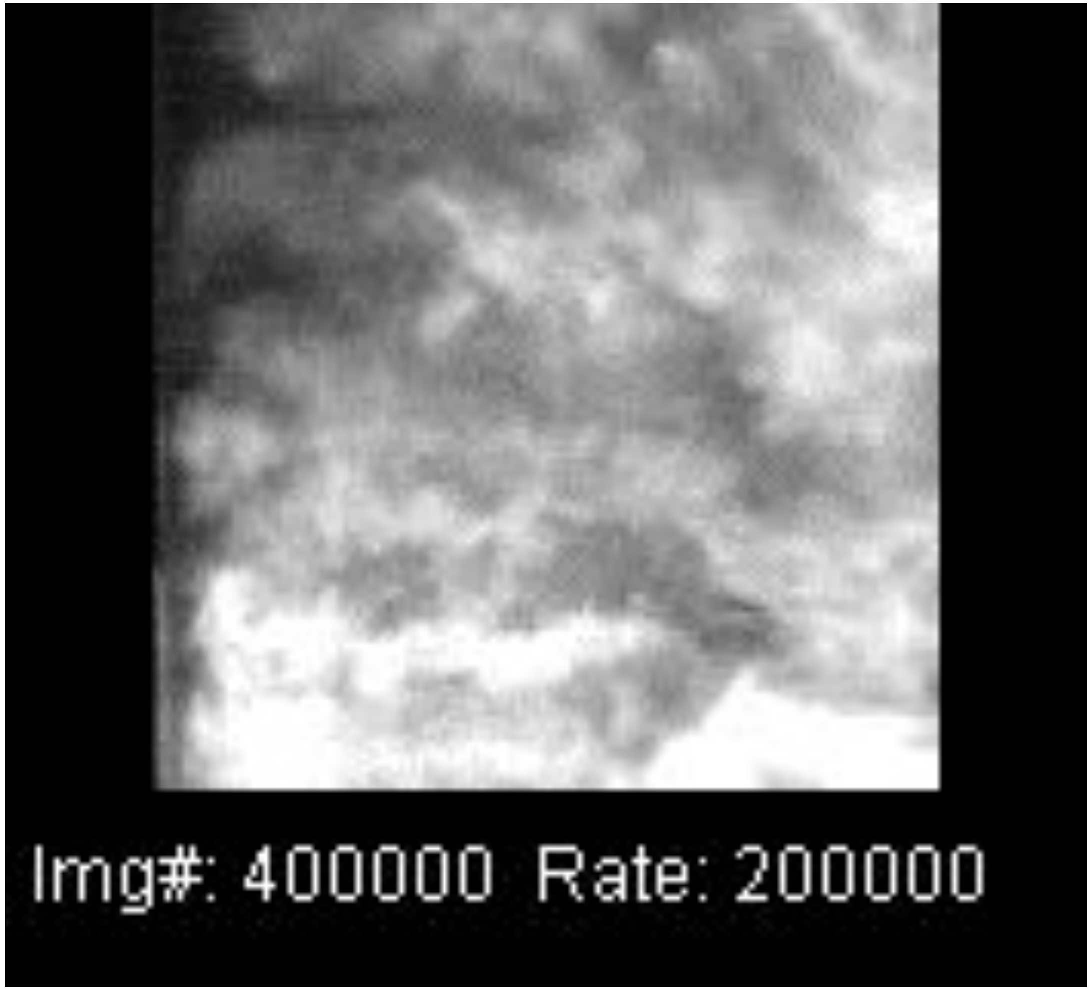
$GCH_4 - GOX \quad \dot{m}_{Total} = 0.2\,\frac{lbm}{sec} \quad \phi = 1.25$



$GCH_4 - GOX \quad \dot{m}_{Total} = 0.2\,\frac{lbm}{sec} \quad \phi = 0.5$

View Through Window

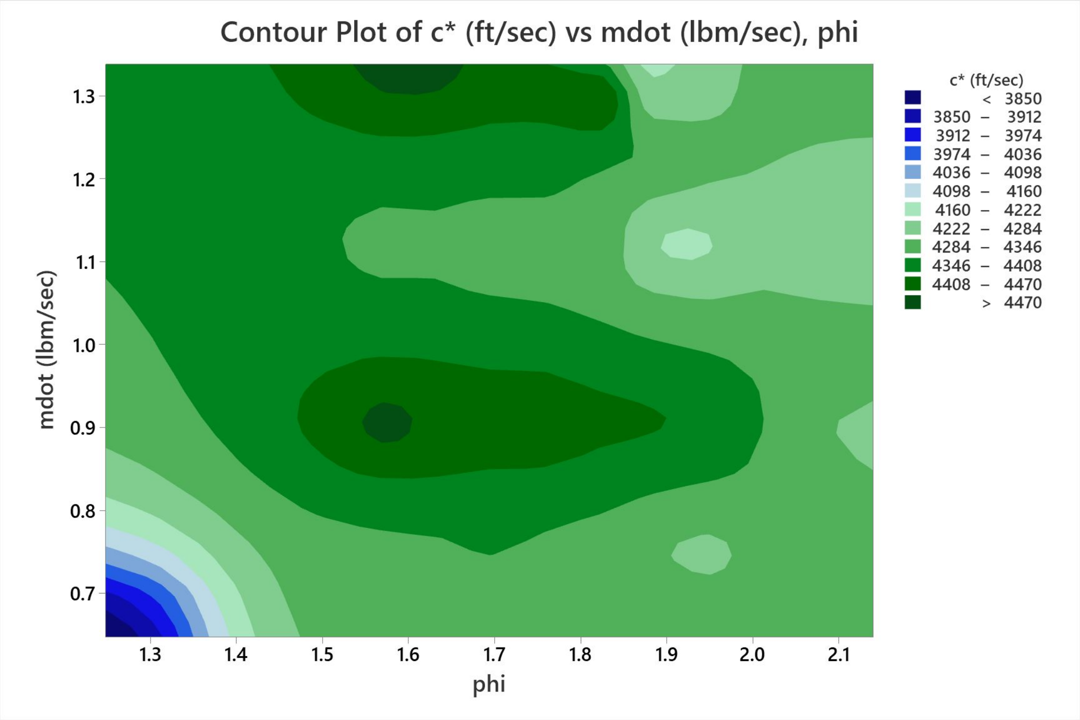




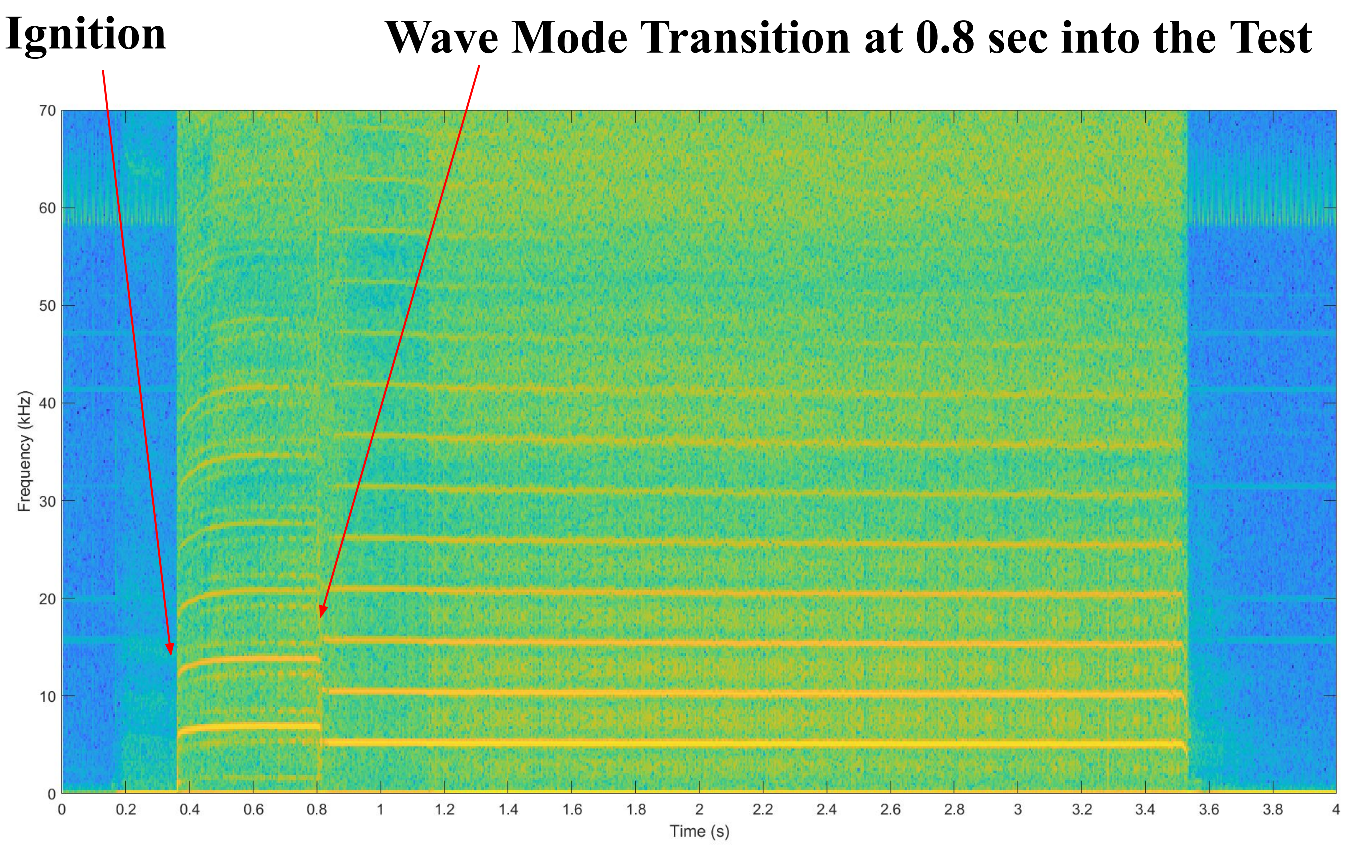
$$GCH_4 - GOX \qquad \dot{m}_{Total} = 0.2\,\frac{lbm}{sec} \qquad \phi = 1$$

Preliminary Results

Initial characterization complete with liquid propane and gaseous methane



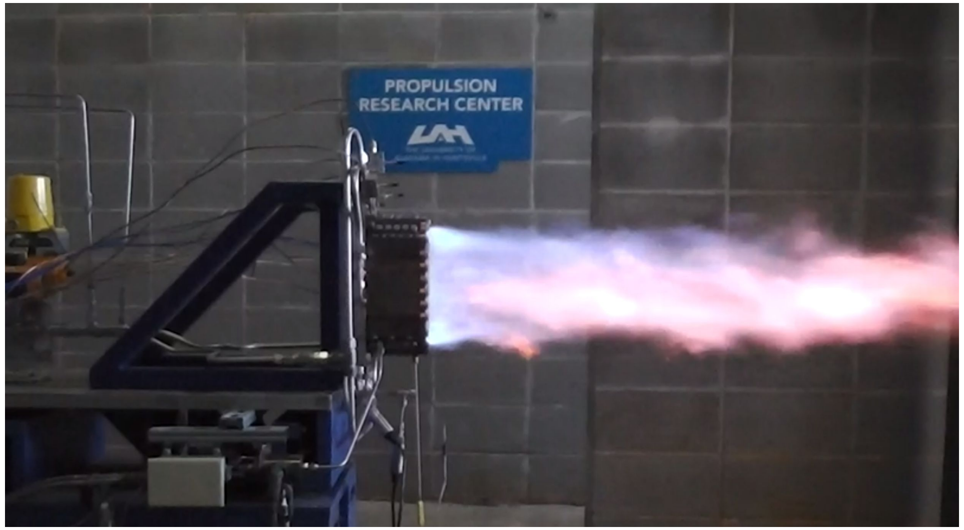
c* Response over a Range of $\dot{m}$ and ϕ with LP/GOX

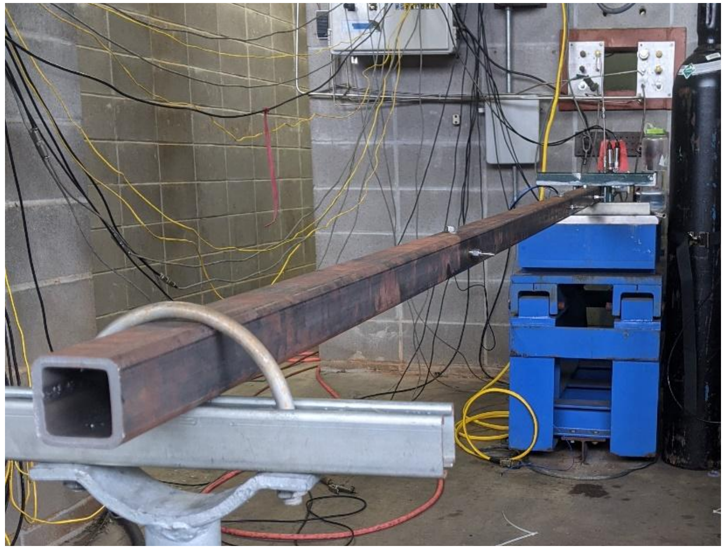


Spectrogram of High-Frequency Chamber Pressure Data GCH_4/GOX

Future Work

- The engine works, but lots of questions
- Injector design
  - Smaller and closer
  - Cold spray atomization
  - Pressure recovery and backflow with linear detonation tube
- Transient plasma
  - Increase detonability by pre-seeding radicals
  - Possible to improve atomization of liquid spray
  - Control det wave speed/strength
- Diagnostics with window
  - Schlieren – shock wave
  - Chemiluminescence – flame front
  - OES, LIF – temperature, species



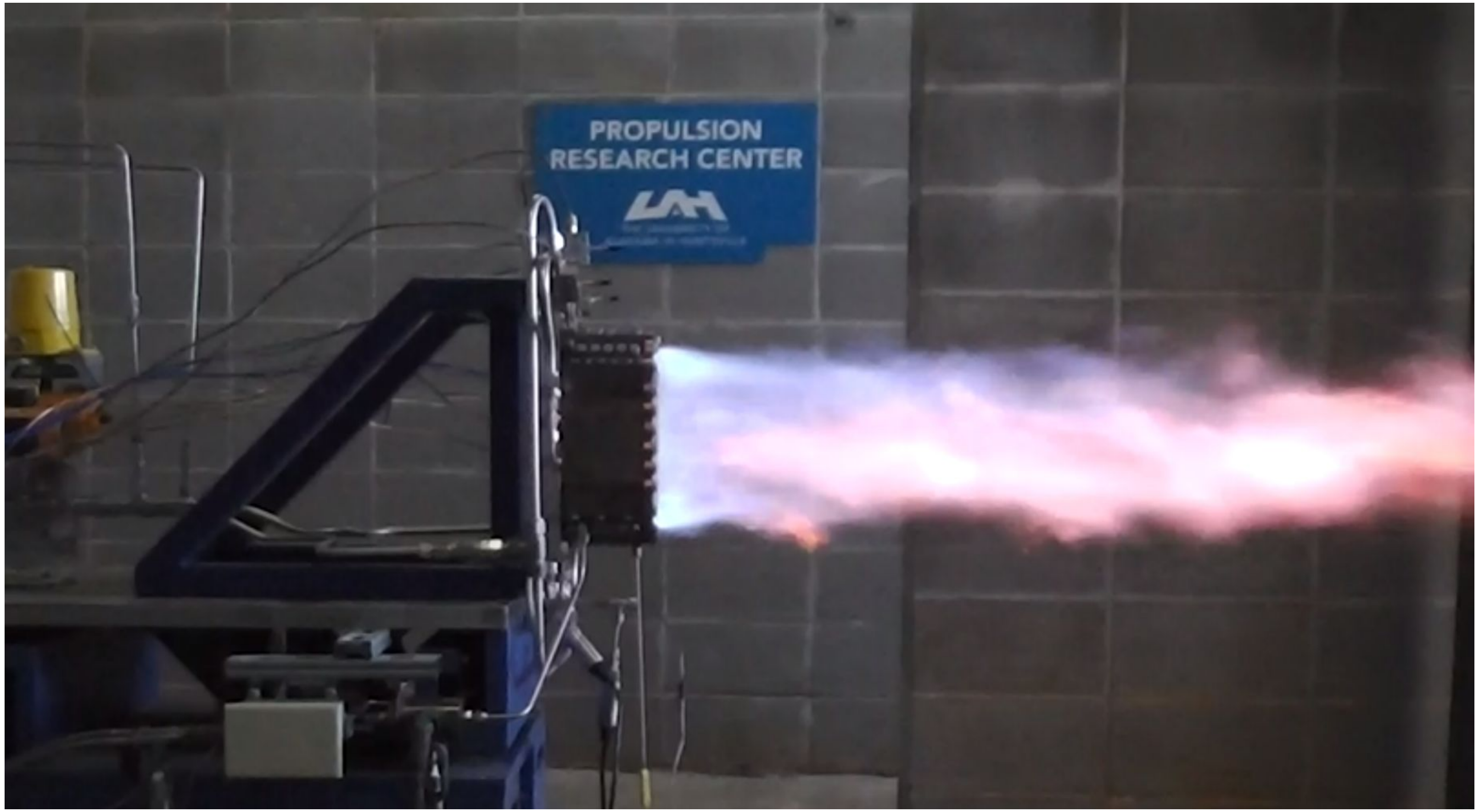


12-ft Linear Detonation Tube

Panel Discussion

Today's Panelist

- **Dr. Gabe Xu**
- Associate Professor of Mechanical and Aerospace Engineering At UAH
- **Mr. Evan Unruh,**
  - Graduate Research Assistant, UAH
- **Mr. Scott Claflin**
  - Aerojet Rocketdyne
- **Dr. John Bennewitz**
  - AFRL



Announcements

Hypersonic Aerodynamics
ONLINE ON-DEMAND: January 2021
Also Available Customized

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE | COLLEGE OF PROFESSIONAL STUDIES

Nitrous Oxide Safety
Spring 2021

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE | COLLEGE OF PROFESSIONAL STUDIES